Holocene aeolian phases and human settlements along the Atlantic coast of southern Spain

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Abstract: A combined geomorphological, radiocarbon dating, archaeological and historical approach permits a refining of the age of the coastal dune systems related to estuaries in the Gulf of Cádiz. Three dune systems are distinguished in this paper. The oldest one, D1, which accumulated under prevailing WSW winds during the first millennium BC, overlays both the occupational horizons of Late Neolithic-Early Copper Age (fourth millennium BC) and the 'lithic workshop levels' (fourth to second millennia BC). The middle dune system, D2, containing both Roman and medieval remains, accumulated between the thirteenth or fourteenth centuries and the seventeenth century AD. The youngest D3 system is associated with the time of building of watchtowers in the seventeenth century AD but extends to the present; it is related to SW prevailing winds. We explain the absence of aeolian deposits prior to ~2700 cal. BP as the result of trapping of a large part of the sediment supply in the estuaries, which starved the neighbouring beaches and aeolian settings. Aeolian accumulation reached significant values when sedimentation in the coastal zone changed from being mainly aggradational in the estuaries (~6500–2700 cal. BP) to mainly progradational in spit barriers and related dunes (post ~2700 cal. BP). The present analysis of aeolian systems suggests a non-direct correlation, at least in some cases, between coastal progradation of spit barriers and aridity.

Key words: Foredunes, aeolian sheets, dunefield, spit barrier, radiocarbon dating, historical evidence, archaeological evidence, climatic change, sea-level change, Gulf of Cadiz, Spain, late Holocene.

Introduction

Borja (1997) differentiated three basic types of littoral dunes in southwestern Spain, according to morphogenetic criteria and taking into account the elementary types of dunes present in each case. Foredunes (coastal dunes) are directly related to beaches. Dunefields usually derive from foredunes but their genesis is related not only to aeolian phenomena but also to the nature and development stage of vegetation. Littoral aeolian sheets are formed by a vertical stacking of broad dunefields separated by palaeosols. These types may extend over hundreds of square kilometres where the elementary dune types are mostly transverse and parabolic dunes. Aeolian and hydrogeological processes – particularly the behaviour of non saturated layers – concur with the genesis of littoral dunes.

Foredunes are coastal dunes or dune ridges oriented parallel to the shoreline, occurring at the landward margin of the beach, along the shoreward face of a beach ridge, or at the landward limit of the highest tide, and more or less completely stabilized by vegetation (Bates and Jackson, 1980). Aeolian foredunes occur associated with beach ridges of coastal plains and spit barriers. As the sand of foredunes derives from the upper foreshore and

backshore, it is widely accepted that the age of a foredune is virtually the same as the age of the beach ridges upon which it was accumulated. If beach sediments are dated, this age may be considered as the maximum age of sand accumulation. However, it is not sure that the accumulation of well-developed foredunes lasts the same time as the deposition of the underlying beach deposits.

The spit barrier systems closing the estuaries offer favourable settings for human settlements owing to their proximity to the littoral and natural harbours (Figure 1). For this reason, archaeological remains are relatively frequent.

In the most complete case found in the Atlantic-Mediterranean linkage area, each spit barrier system is formed by four coastal morpho-sedimentary units (spit barriers) that Zazo *et al.* (1994) named H_1 to H_4 (Figure 2). Beach crests and swales on the surface of each unit are arranged in sets separated by erosional surfaces and/or particularly large swales that Zazo *et al.* (1994) called a gap. Numerous radiocarbon measurements allowed to deduce the age of the four spit units (Zazo *et al.*, 1994; 1996a; Goy *et al.*, 1996; Rodríguez-Ramírez *et al.*, 1996; Lario, 1996). In this paper we use the ages of these units expressed as cal. BP: H_1 (6500–4700 cal. BP), H_2 (4400–2700 cal. BP), H_3 (2400–700 cal. BP) H_4 (500 cal. BP– present).

This paper has a double aim: (1) to identify periods of increased and reduced aeolian deposition during the middle and recent Holocene in the Gulf of Cádiz, located at the southwestern Atlantic littoral of Spain (Figure 1) based on the study of dune systems; (2) to place these periods in a chronological sequence based upon radiocarbon dating, archaeological remains and historical data, and to relate them with the climatic and sea-level changes that took place during the last 6500 yr BP.

All radiocarbon data are listed in Dabrio *et al.* (1999). We use AMS and α-spectrometry radiocarbon data from marine shells, peat and vegetal remains. In order to compare radiocarbon dates with archaeological data all radiocarbon data have been calibrated using the CALIB software (Stuiver and Reimer, 1993). Previously, reservoir effect have been corrected in marine samples ($R = -440 \pm 85$ yr in this area; Dabrio *et al.*, 1999).

Results

Foredunes and associated small dunefields in Ayamonte (Isla Canela) estuarine barrier

The estuarine barrier of the rivers Guadiana (on the Spanish border with Portugal) and Carreras (Figure 3) includes the spit barrier units H_2, H_3, and H_4, present largely in the Isla Canela area. The innermost, oldest recognizable deposits of the spit unit H_2 have been dated as 2950 cal. BP (Figure 2), but archaeological remains of lithic industries forming the so-called 'lithic workshop levels' dated as fourth to second millennia BC (Gómez *et al.*, 1993) suggest the existence of an occupation level in the spit prior to 2950 cal. BP (but still H_2 in age).

According to this, the accumulation of parabolic dunes and foredunes recognized as D_1 began *c.* 3000 cal. BP, and finished before 930 cal. BP (the oldest age dated in H_3 and the overlying related foredunes).

The Isla Canela-Punta del Moral dune system (D_2) found south of El Pinillo unit is related to the spit unit H_3. Although the oldest age dated in the H_3 beach deposits in this area is 930 cal. BP, they contain remains of a human settlement and a mausoleum of Late Roman age (third to fourth centuries AD). These remains suggest that the spit was big enough at that time to accept such stable buildings. The dunes of system D_2 incorporate remains of buildings and cover the already deteriorated walls of the mausoleum. This proves that they accumulated after the fourth century. However, we consider that they actually accumulated after the tenth century (post-930 cal. BP) because at that time the spit barrier was still prograding. The most recent age of dune system D_2 can be fixed because it is older than the Torre Canela watchtower built in the seventeenth century but is covered by younger (D_3) aeolian dunes containing many postmedieval remains of ceramics (Borja, 1992).

The D_3 aeolian system consists of foredunes and some poorly developed transverse dunes related to the most recent prograding phase (H_4) of the spit which took place in the last 200 to 300 yr, as demonstrated in Torre Canela (see above). The system D_3 is best represented to the south, between Punta de la Espada and Punta del Caiman. In this area it is separated from D_2 by tidal flats (marismas de San Bruno).

Foredunes and dunefields in Punta Umbría-Punta Arenilla estuarine barrier (Huelva)

The Odiel-Tinto estuary is almost separated from the open sea by a complex estuarine barrier formed by the Punta Arenilla and Punta Umbría spit systems, and Saltés Island (Figure 4). There are aeolian foredunes and dunes mostly of transverse type, with some parabolic and a few barchans.

The oldest (albeit indirect) indication of spit sedimentation comes from cores (Zazo *et al.*, 1996b) drilled in Las Madres coastal lake. The lake, a former marine bay (lagoon), was already separated from the sea at 6290 cal. BP (Figure 2). We assume that the separation was produced by beach ridges belonging to the H_1 unit of Punta Arenilla spit (much in the same way as present coastal configurations in the area) that do not crop out nowadays. The system D_1 in Punta Arenilla consists of parabolic dunes that migrated under winds blowing from the WSW after 6290 cal. BP. But, as dunes covered a 'lithic workshop level' of fourth to second millennia BC, their age must be necessarily younger, and should be associated to the progradation of the spit systems H_2/H_3, but when exactly? Radiometric data indicate that the sedimentation of H_2 in Punta Arenilla and Punta Umbría took place after *c.* 3000 BP. Mapping (Figure 4) allows us to infer that its upper limit is coeval with the oldest beach ridges in spit system H_3.

The aeolian system D_2 consists of foredune and large transverse dunes, particularly well exposed in Punta Umbría spit. In Punta Arenilla they cover older (D_1) dunes. The youngest dune systems overlaid by these dunes are of H_3 age. Dune generation continued until around the seventeenth century when the Torre Umbría watchtower was built.

The youngest aeolian system (D_3) includes several ridges of foredunes in Punta Umbría. In Punta Arenilla there are also barchans, which are exclusive to this area. Dune generation in this system is related to the progradation of the spit unit H_4 in the last three centuries.

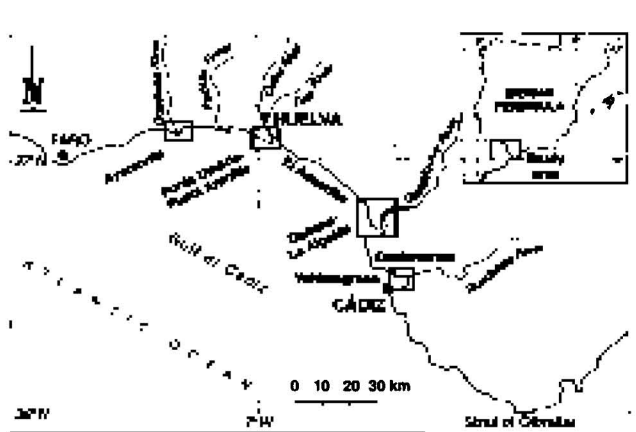

Figure 1 Location map of the study area and localities cited in the text.

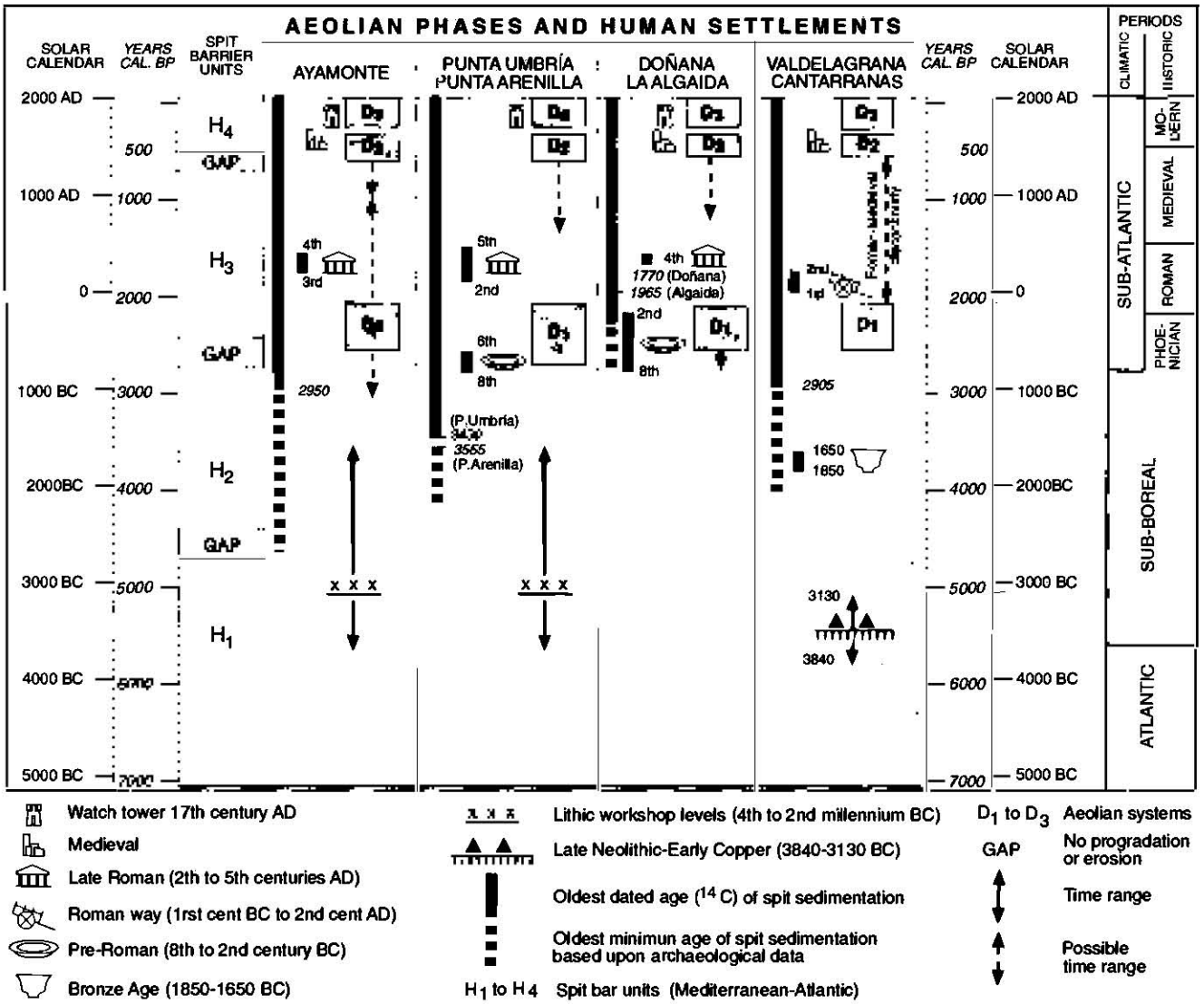

Figure 2 Chronostratigraphy of aeolian phases and human settlements in the Gulf of Cádiz. Note that italic typing indicates calibrated ages.

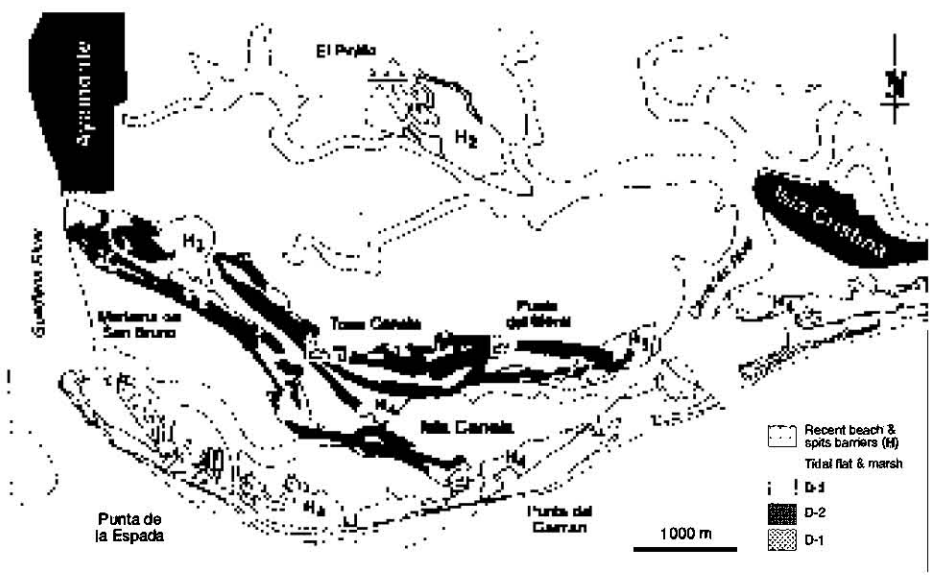

Figure 3 Foredune systems between Ayamonte and Isla Cristina, in the Spanish (eastern) side of the Guadiana estuary.

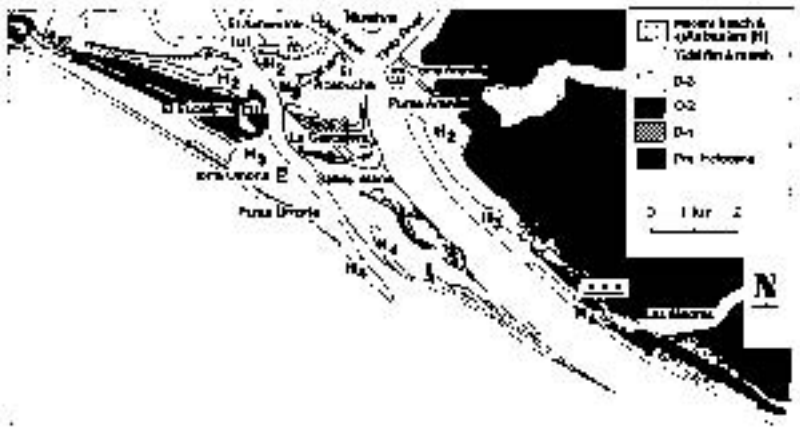

Figure 4 Foredunes and dunefields in the complex Odiel Tinto estuarine barrier formed by the spits of Punta Umbría and Punta Arenillas. Archaeological data in Saltés Island after Rubio *et al.* (1997).

Foredunes in Doñana-La Algaida estuarine barrier (provinces of Huelva and Cádiz)

The spit barrier systems of Doñana and La Algaida separate the estuary of the Guadalquivir river from the open sea (Figure 5). A pre Roman settlement found in La Algaida dated as eighth to second centuries BC (Menanteau, 1979) indicates that sedimentation of the spit unit H_2 began before this date. In contrast, the oldest radiocarbon age obtained in La Algaida is 1965 cal. BP (Figure 2), that corresponds to shells deposited later.

The record of aeolian dunes in this area includes small occurrences of the D_1 system in La Algaida, related with spit system H_2, and the well developed, and partly superposed, D_2 and D_3 systems of Doñana (Figure 5).

The aeolian system D_2 includes semistable parabolic dunes moved by WSW winds, that maintain at present some mobility on the lee sides. These dunes bury (fossilize) the Roman settlement of Cerro del Trigo, but also include medieval archaeological remains.

The youngest system (D_3) consists of transverse dunes moved by prevailing SW winds. The dunes partly cover the coastal watchtowers built in the seventeenth century and occur associated with beach ridges that prograded after the construction of the towers. Two of these towers currently lie hundreds of metres from the shore (Torre Zalabar is 170 m from the sea, and Torre de San Jacinto some 600 m; Figure 5) demonstrating rates of coastal progradation up to 4 m/yr for the last 300 years.

Foredunes of Valdelagrana and the aeolian sand sheet of Cantarranas (Cádiz province)

In addition to the foredune systems of Valdelagrana spit barrier, we have included in our study the Cantarranas littoral aeolian sheet owing to the archaeological richness of the area around Puerto de Santa María (Figure 6). The littoral aeolian sand sheet

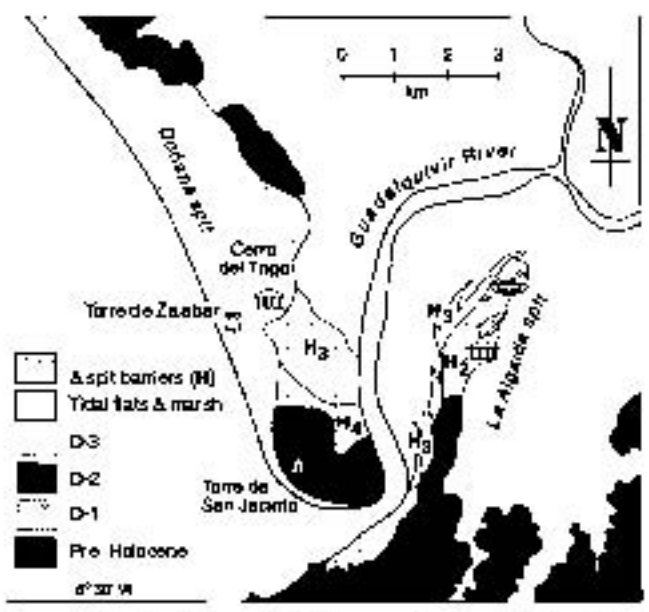

Figure 5 Foredunes in the spits of Doñana and La Algaida in the barrier of the Guadalquivir estuary. Archaeological data after Menanteau (1979).

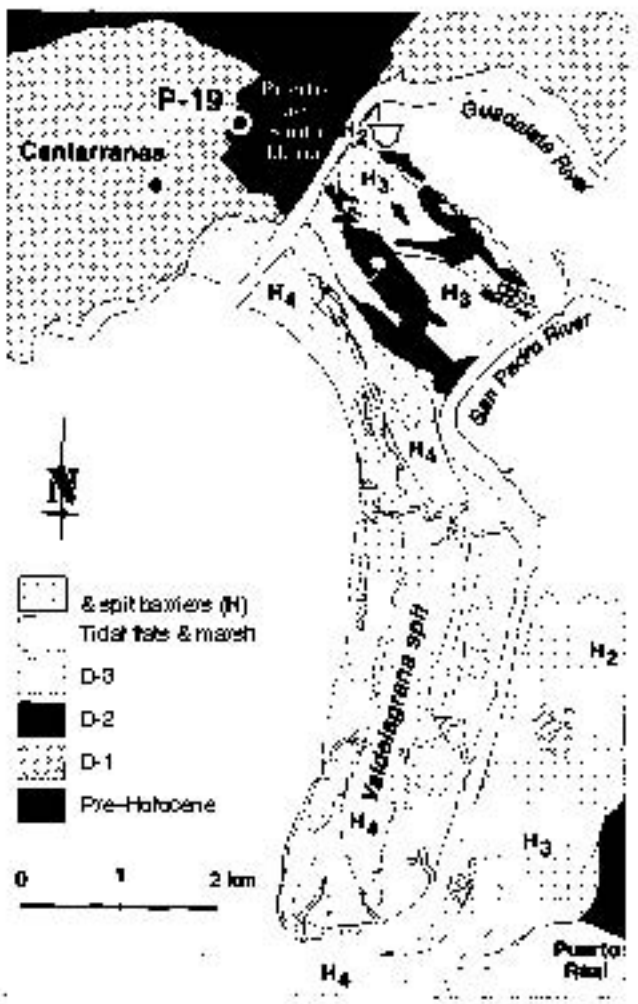

Figure 6 The foredunes of Valdelagrana spit (the estuarine barrier of the Guadalete river) and the aeolian sheet of Cantarranas close to El Puerto de Santa María

extends for some 10 km northwest of Puerto de Santa María, and penetrates several kilometres inland.

Archaeological remains included or related to the littoral aeolian sheet were collected in the archaeological sites of Cantarranas (Borja, 1992; Díaz del Olmo *et al.*, 1993) and P-19 in Puerto de Santa María (Borja *et al.*, 1997). According to Borja *et al.* (1997), the synthetic sequence here is as follows (Figure 2). The substratum consists of Pleistocene calcarenites and/or marlstones, topped by a weathered layer (red soil). Above this is an occupational horizon (Figure 7) of Late Neolithic-Early Copper (fourth millennium BC) age. This horizon is covered by the D_1 aeolian deposits. The oldest dated age of the dune system is the first millennium BC because it contains archaeological remains of several cultural phases between the sixth and the second centuries BC. Above these, there are remains of a salting factory for fish used in several periods. The last time this was used was between the fourth and the early second centuries BC (Figure 8).

In the Valdelagrana spit, the dune system D_1 is less developed (Figure 6). It is mostly associated with the spit unit H_2 whose oldest radiometric age is 2905 cal. BP, but a site of Bronze Age (1850–1650 BC; Figure 2) found in H_2 indicates that the spit existed prior to 3500 BP (Gómez Ponce *et al.*, 1997).

Remains of a Roman road constructed between the first century BC and the second century AD (Gómez Ponce *et al.*, 1997) crossing the spit units H_2 and H_3 (Figure 6) offers further proof of the ages proposed for the spit units.

The foredune system D_2 yields late medieval remains corresponding to an interval ranging from the late fifteenth to early seventeenth centuries AD. The dune systems D_1 and D_2 are separated by a regional discontinuity evidenced by an organic soil. The discontinuity lasted at least from the first century BC to the fourteenth century AD. The most recent foredune system (D_3) occurs related to the spit unit H_4 that was deposited in the last 500 yr. In Cantarranas, dunes of the system D_3 fossilize ruins of houses dated as seventeenth century AD (Borja *et al.*, 1997) and crown the interior morphologies of the littoral aeolian sheet.

Figure 7 '*In-situ*' Mañá-Pascual A-4 amphorae of the salting factory for fish (fourth century BC) found in archaeological site P-19 (Puerto de Santa María, Cádiz, Spain). After Borja *et al.* (1997).

Discussion

Aeolian dunes occur more or less continuously along the coast of the Gulf of Cádiz, and are particularly well developed between the estuaries of Odiel-Tinto (Huelva province) and Guadalquivir (Huelva and Cádiz provinces) rivers, covering the El Asperillo cliffs (Figure 1). Six aeolian units with ages ranging from Late Pleistocene to present have been distinguished. These aeolian units are limited by erosional supersurfaces associated with weathering profiles that are interpreted as periods with aeolian activity when deposition of sand was not significant; this is demonstrated by erosion of the underlying deposits (Zazo *et al.*, 1997).

In this paper we have studied the foredune systems associated with the spit barrier systems of Ayamonte-Isla Canela, Punta Umbría-Punta Arenilla, Doñana-La Algaida, and Valdelagrana, and the littoral aeolian sand sheet of Cantarranas in the Guadalete river mouth. As their genesis is closely related to the recent evolution of the Guadiana, Odiel-Tinto, Guadalquivir and Guadalete estuaries respectively (Figure 1), a correlation with aeolian deposits accumulated far away from estuarine settings (Zazo *et al.*, 1997) is only possible for the more recent units, that were deposited after the trapping effect of estuaries decreased and significant coastal progradation took place.

We record the maximum of the Flandrian transgression (~6500 ^{14}C yr BP) as the maximum advance of estuarine barriers into the estuary basin (Dabrio *et al.*, 1999), or the maximum sea-level elevation (around the present 0 m level) in non-estuarine Mediterranean coasts (Zazo *et al.*, 1994). After that, up to four spit barrier units were deposited in the most complete cases: H_1 (6500 to 4700 cal. BP), H_2 (4400 to 2700 cal. BP), H_3 (2400 to 700 cal. BP), H_4 (500 cal. BP to present) separated by periods of no deposition and/or coastal erosion, indicated by gaps in the prograding pattern.

Only the three youngest spit barrier units have been observed so far along the Atlantic coasts of the Iberian Peninsula, where our study area is located (Zazo *et al.*, 1994; 1996a; Goy *et al.*, 1996). This is due to the prevalence of coastal aggradation as compared with progradation between ~6500 and 2700 cal. BP (Goy *et al.*, 1996; Zazo *et al.*, 1996a). Recent results including the study of 19 drill cores from Odiel-Tinto and Guadalete estuaries (Dabrio *et al.*, 1999) have confirmed the generation of the maximum flooding surface inside the estuaries between 7000 and 6000 cal. BP, capping the Flandrian transgressive systems tract. The absence of H_1 deposits in the Atlantic spit barrier systems is due to trapping of a large part of the fluvial sediment supply into the central basins of estuaries during the highstand.

Three aeolian dune systems, called D_1, D_2 and D_3 in ascending stratigraphic order, that include foredunes, dunefields and littoral aeolian sheets have been distinguished. The age of these dune systems have been deduced from the ages of the spit barrier systems (H) with which they are associated, and the archaeological and historical remains that they contain.

According to these data, accumulation of aeolian systems (D_1) began ~2500 cal. BP (*c.* 600 yr BC) shortly after a firm emerged substratum of H_2 age existed. They formed continuous ridges above the storm surge levels of the beach barriers or littoral aeolian sheets near the estuaries. This is the case of site 19 (Puerto de Santa María, Cádiz), where the archaeological record includes several cultural phases (Figure 2). The aeolian system D_1 ended

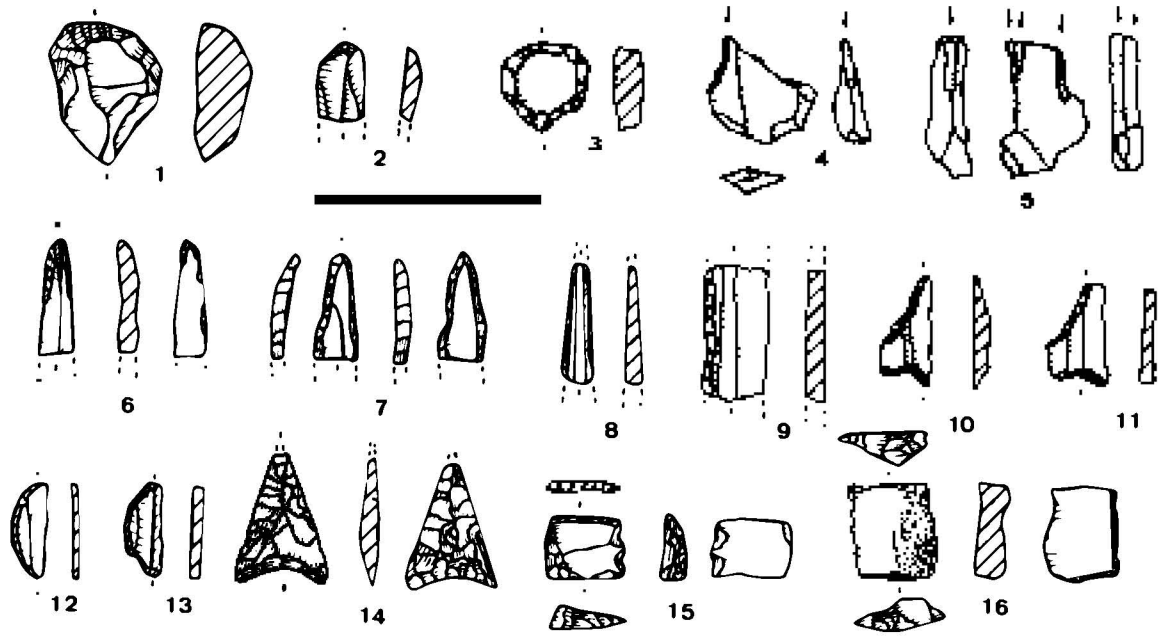

Figure 8 1 to 16: Late Neolithic-Early Copper artefacts from Cantarranas site (Cádiz). After Díaz del Olmo *et al.* (1993).

in the early second century BC as suggested by amphorae of the salting factory for fish. The beginning of deposition must coincide with noticeable changes of the coastline which took place at ~2700 cal. BP caused by a shift in palaeowind directions from the W to WSW (Zazo *et al.*, 1996a; Goy *et al.*, 1996). This triggered a large coastal drift to the east. After this time, spits growing to the east and southeast prevailed over the ones accreting in opposite directions in all estuaries (Figures 3 and 4).

The absence of aeolian sediments between *c.* 6500 cal. BP and *c.* 2500 cal. BP may be related to the evolution of estuaries and their limiting estuarine barriers in the area. During the deposition of the spit unit H_1 most sediments were trapped in the inner parts of the estuaries. This means that sediment supply to the estuarine barriers was not very important and these were largely reworked by lateral shifting of the tidal inlet (estuarine channel). This is a reasonable explanation for the absence of subaerial record of the spit system H_1 in the Gulf of Cádiz. During deposition of the spit system H_2 sedimentation took place mostly in the axial zones and sediment supply increased, improving the preservation potential of the subaerial parts of the spits (Dabrio *et al.*, 1999).

Archaeological data from site P-19 suggest that accumulation of the system D_1 took place between the late sixth and early second centuries BC.

The beginning of the next system is more difficult to establish but, according to data from site P–19, there is a sedimentary hiatus of regional extent marked by an organic palaeosol that separates the aeolian systems D_1 and D_2. This break in sedimentation has been referred to as the 'Roman-Medieval discontinuity' (Borja *et al.*, 1997). The end of this episode is well observed in all the studied areas as ceramic remains of post-medieval age (late fourteenth to early seventeenth centuries AD) are included in sediments of the D_2 system indicating that the probable age of this system is between the fourteenth and seventeenth centuries AD (Figure 2). Prevailing winds during this phase were from WSW.

Sedimentation of aeolian system (D_3), began around the early seventeenth century, when the watchtowers were built, and continues at present under prevailing wind directions from the SW.

The only climatic data available were obtained from pollen analysis in the Las Madres coastal lagoon (Zazo *et al.*, 1996b). Vegetation assemblages record a first change from ~6290 cal. BP to more arid conditions *c.* 4000 cal. BP and a second, and more important, *c.* 900 cal. BP, when peat ceased to accumulate. Moreover, Stevenson and Harrison (1992) founded main environmental changes at similar ages, but they assumed that these changes are related to human influence. Probably, climatic changes conditioned the agricultural management in this area and both causes together influenced over the abrupt changes in the environment and landscape.

Following Zazo *et al.*'s (1994) conclusions, the spit barrier units H, generated during phases of coastal progradation, have been related to periods of still stand of gently falling sea level and more arid climate. The intervening gaps (no progradation and/or coastal erosion) have been correlated with periods of sea-level rise under low-pressure atmospheric conditions. The relations of aeolian dune systems (D) with the coastal units H (Figure 2) suggest that aeolian accumulation began at the end of gaps, when the larger availability of sand favoured wind transport. However, the regional 'Roman-medieval discontinuity' marked by an organic palaeosol separating the aeolian systems D_1 and D_2 suggests more humid conditions during most of deposition of system H_3 and opposes a direct correlation between coastal progradation and aridity as previously assumed.

Conclusions

Archaeological and historical data supplied in this paper confirm the duration of the accumulation of spit barrier units (H) defined by Zazo *et al.* (1994; 1996a), Lario (1996), and Goy *et al.* (1996) in the area connecting the Atlantic and the Mediterranean. In some cases, these remains allowed the ages obtained using radiocarbon measurements to be refined for progradation of any of the spit units (H) in some spit barrier system. Particularly useful were the 'lithic workshop levels' developed between the fourth and the second millennia BC, the Bronze Age sites (1850 to 1650 BC), and the pre-Roman remains (Figure 2). All these yielded ages for the beginning of spit systems (indicative of coastal progradation in a given estuary) more accurate than the existing radiocarbon data.

Our present data indicate that the Guadalquivir estuary kept a more direct relation with the open sea until more recent times (*c.* 2000 BC) compared with the other studied estuaries.

Three aeolian systems D_1, D_2 and D_3, in ascending stratigraphic order, have been distinguished. The aeolian systems D_1 (~2700 cal. BP to ~2000 cal. BP, i.e. first millennium BC) and D_2

(fourteenth to seventeenth centuries AD) accumulated under prevailing winds from the WSW. They are separated by a regional 'Roman-medieval discontinuity' marked by an organic palaeosol. The youngest aeolian unit (D_3) was accumulated by prevailing winds from the WSW, mostly during the building of the watchtowers of the seventeenth century AD.

The absence of aeolian deposits prior to ~2700 cal. BP is caused by trapping of a large part of the sediment supply to the coast into the estuaries.

Aeolian systems began to accumulate during the gaps separating phases of progradation of coastal units recognized in previous papers (Zazo *et al.*, 1994; 1996a; Lario, 1996; Goy *et al.*, 1996). Gaps correspond to periods of higher sea level during long-lasting cyclonic (low-pressure) conditions. However, the organic palaeosol developed during the regional 'Roman-medieval discontinuity' (~2000 cal. BP to 700 cal. BP), largely coeval with the spit barrier unit H_3, discourages previously suggested direct correlations between aridity and beach progradation and between humidity and gaps.

However, after the fourteenth century AD, during the accumulation of dune systems D_2 and D_3 (spit barrier unit H_4) the pollen record of Laguna de Las Madres suggests more arid conditions recognized in the area, but increased anthropic impacts during this time may also be of importance.

Acknowledgements

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